"Interaction of the Kuroshio with the East and the South China Seas"
and
"Nonlinear Wave Dynamics in the South China Sea"

Pearn P. Niiler
Scripps Institution of Oceanography
9500 Gilman Drive , MC 0213, La Jolla, CA 92093-0213
Phone: (858) 534-0378 ; email: pniiler@ucsd.edu

Dong-Kyu Lee
Department of Marine Sciences, Pusan National University
Busan, 609-735, Korea
Phone: (51)510-2180 Fax: (51)581-2963 email: lee@east.ocean.pusan.ac.kr

Luca Centurioni
Scripps Institution of Oceanography
9500 Gilman Drive, MC 0213, La Jolla, CA 92093-0213
Phone: (858) 534-6182; email: lcenturioni@ucsd.edu

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LONG TERM GOALS

The long-term objective is to better understand the interactions between the Kuroshio and the China Seas with the coordinated use of several tools, some of which already developed by ONR: a numerical model, a Surface Velocity Program (SVP) drifters array and surface drifters that are configured to gather enhanced data. We intend to investigate the dynamical processes that govern this interaction. To achieve this goal, new observations are being obtained. A range of model parameters will be tested to find the combination that best represents the observed surface circulation. This research contributes to a more realistic prediction of this complex physical environment in area of strategic importance for PACFLEET operations.

OBJECTIVES

The first objective is to obtain accurate velocity measurements at 15 m depth in the South China Sea and in the Luzon Strait region, in order to achieve more accurate Fall and Winter measurement of the existing current systems and of the upper ocean mass transport through the Luzon Strait. The second objective is to use the existing and new datasets of surface circulation to compare with the results of the ROMS numerical model to evaluate the model ability to reproduce a realistic flow field. A third objective is to utilize drifting platforms to make velocity and temperature profile observations of high amplitude, short period internal waves.

APPROACH

To accomplish the first objective, SVP drifters were assembled in Korea and were deployed from 2003 through 2006 in the Luzon Strait region during the inflow regime of the October-January period. In the

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3rd year, the currents at 150 m were also measured with drifters. These measurements determine accurately the current systems of the SCS and aspects of the dynamics of the in-and-out flow through the Luzon Strait. To accomplish the second objective, various runs of the numerical model, made under an appropriate range of settings and forcings, are analyzed in terms of the East China Sea budget of mass, vorticity and thermal, potential and mechanical energies. The model set-up and the simulations are being performed by Prof. Lee and the drifter's data analysis is being performed by Dr. Luca Centurioni. They will both perform the interpretations of the drifter data and the comparison with the model outputs together with the principal investigator, Prof. Peter Niiler. Regarding the Internal waves experiment, Dr. Luca Centurioni and Prof. Peter Niiler have processed and started the interpretation of the data collected during the NLIWI '05 pilot experiment with the goal of measuring the non-linear terms of the IW flow.

WORK COMPLETED IN YF'06

In Fall and Winter of '05-'06, 75 SVP drifters and an additional 75 drifters drogued at 150 m depth were deployed in the Luzon Strait from the ships operated by Hanjin Shipping Co thus completing the field work phase. The data were reduced and the mean geostrophic surface flow in Fall and Winter was computed together with several other quantities, including the mean and eddy energy level. All of the available hydrographic measurements in the region were used to compute the geostrophic mass transport referenced to the surface through the Luzon Strait in the upper 1000 m (in collaboration with Prof. Vitalii Sheremet).

Configuring ROMS for integration in the East China Sea with horizontal resolution of 5 km was completed last year. The model is initialized and forced at the boundaries by 1/4° monthly hydrographic data from new NOAA climate data set, monthly wind from QUIKSCAT and mean sea level derived from historical drifter data (Maximenko and Niiler, 2005). New for this year are several experiments with synthetic drifters and neutrally buoyant particles.

Finally, a suite of computer programs specifically designed to reduce the data from the '05 NLIW pilot experiment was developed and the data were analyzed and put in context with the trajectories from GPS fixed drifters that were deployed simultaneously.

RESULTS

Surface currents and volume transport in the Luzon Strait

Three years of drifter velocity observations (Figure 1) at 15m depth indicate an average of 60 cm/sec inflow to the South China Sea (Figure 2).

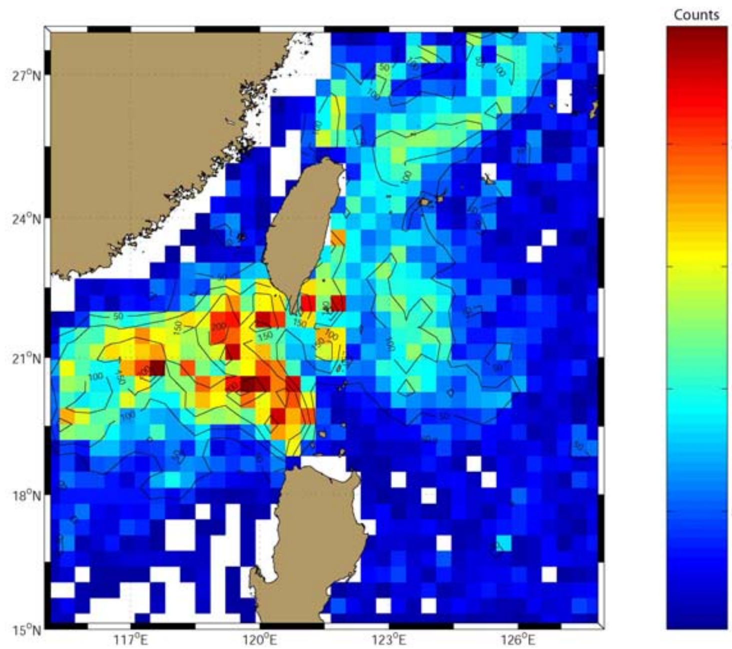

Figure 1: Number of observations (ONDJ) in 0.3°X0.3° bins between 11/10/1987 and 01/31/2006. The region with higher number of observations, west of the Luzon Strait, shows the dataset enhancement that came from this project, with drifters released between 2003 and 2006.

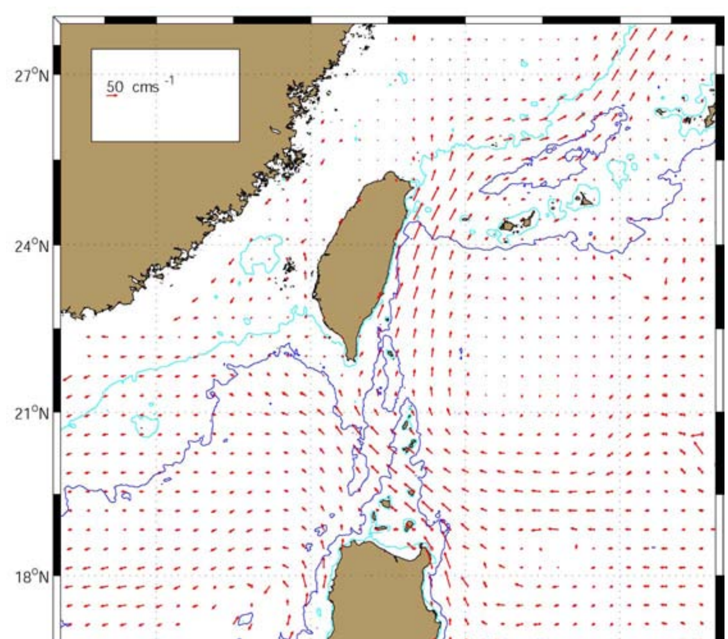

Figure 2: Mean velocity field (ONDJ) at 15 m depth (0.3°X0.3° resolution averaged between 11/10/1987 and 01/31/2006.

The 15 m depth geostrophic velocity field, obtained by subtracting the Ekman currents (Figures 3 and 4) is used as a reference level to compute the geostrophic volume transport across the Luzon Strait (Figures 5). This preliminary computation indicates an inflow of about 5.7 Sv from the surface to 450 m. An error analysis is being performed to compute the maximum depth at which transport estimates are statistically significant.

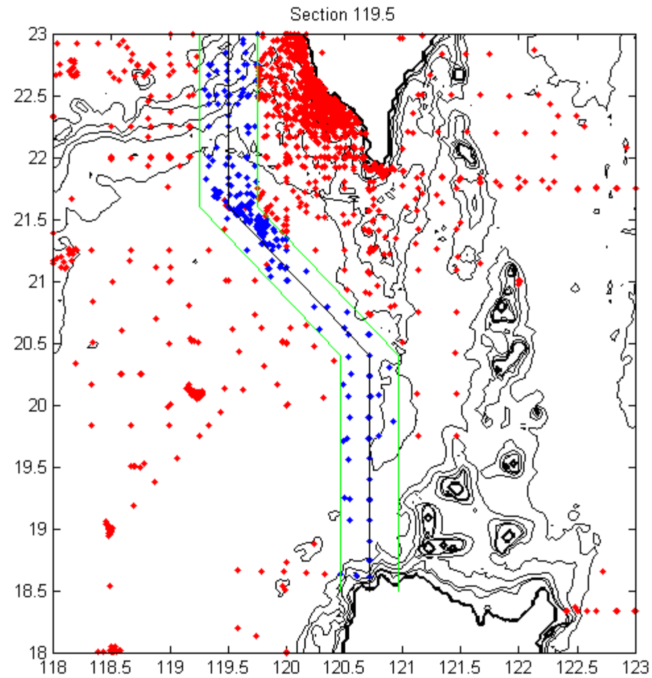

Figure 3: The transect used for the computation of the volume transport. The CTD casts that were used to compute the geostrophic shear for the ONDJ period are shown in blue.

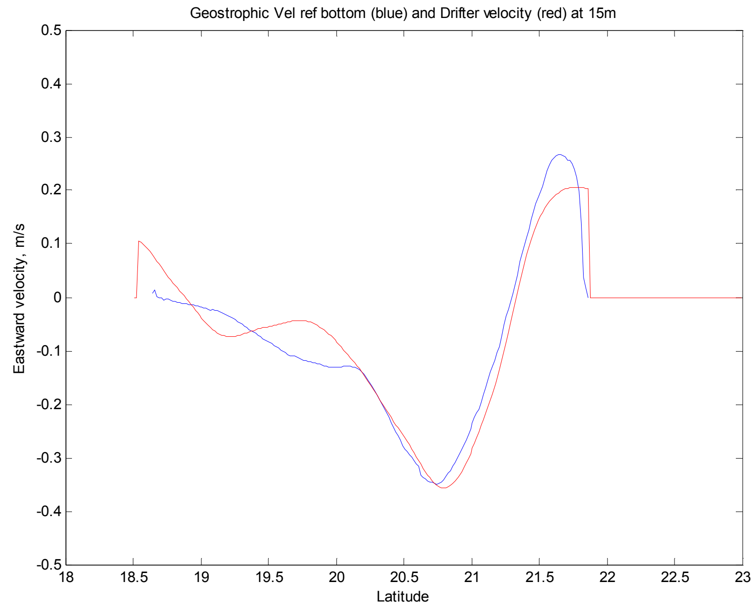

Figure 4: Geostrophic velocity normal to the transect shown in figure 3 at 15 m depth (ONDJ average). Red is from drifters and blue is from hydrography referenced to 5500m or bottom.

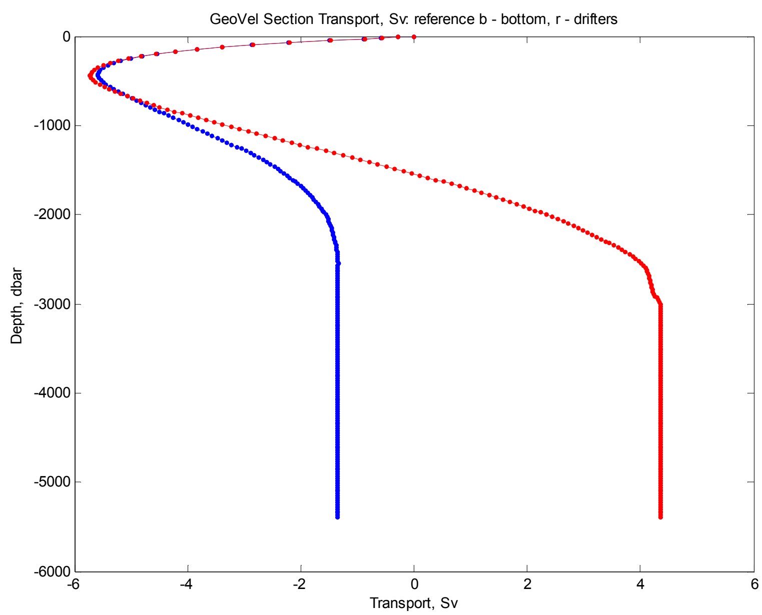

Figure 5: Geostrophic volume transport from hydrography referenced to drifters (red) and bottom (blue).

Modeling

The analysis of ROMS results focused on the fluxes between Kuroshio and the East China Sea and focused on experiments performed using drifter deployment at various depths and tracer release in the

inflow region east of Taiwan. When isobaric drifters at 15m depth were released in the Kuroshio inflow region, no drifter was escaped to the ECS from Kuroshio (Fig. 6). Real drifter deployments in the Kuroshio showed same result. But many neutrally buoyant drifters were intruded into the shelf especially at the southwest of Kyusyu (Fig. 7). Tracer released in the Kuroshio inflow region shows clear influx of Kuroshio water into the shelf in the region southwest of Kyusyu where Kuroshio leaves 150m depth contour and deflects eastward (Fig. 8). The dynamic calculation of vorticity, eddy energy and mass fluxes along the shelf boundary are undergoing using history data of ROMS run.

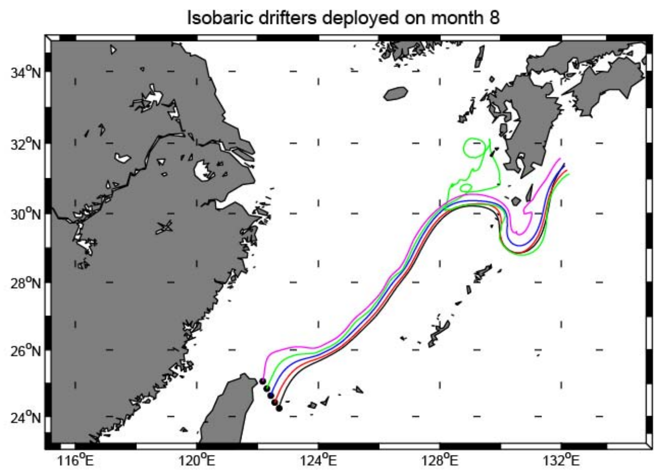

Figure 6: Tracks of isobaric drifters deployed at 15m.

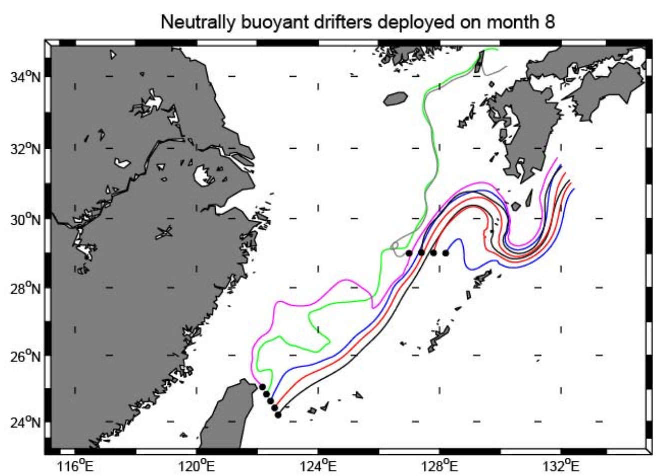

Figure 7: Tracks of neutrally buoyant drifters deployed at 15m.

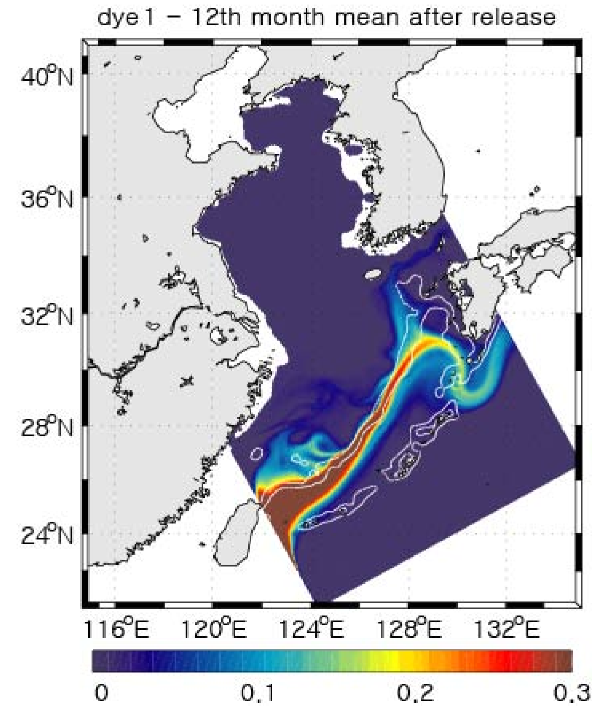

Figure 8: Tracer concentration in 12th month after continuous release in the Kuroshio inflow region.

NLIW in the Luzon Strait

The ~5 days long tracks of 2 drifting chains and 19 SVP drifters used for NLIW '05 are shown in Figure 9. Note the greater distance traveled by the SVP drifters during the same time interval. The cycloidal path is the signature of the tide. Eight selected trajectories (Figure 10) illustrate very different processes that occur in the SCS and at its boundaries, such as strong internal tides, vigorous stirring by the mesoscale eddy field and interaction of mesoscale structures with the Kuroshio. The drifters, deployed within 19 km of each other, moved coherently to the south-west/west for about 6 days until they started to separate into 3 groups. The Summer monsoon in 2005 was established by June 15 and the associated Ekman currents pushed the drifters north-eastward. All drifters exited the SCS following very different routes. The ones that exited through the Taiwan Strait are shown in blue, while the red and the green trajectories are the drifters that exited through the Luzon Strait (Centurioni et al 2006). The temperature plot from one of the chains (figure 11) shows that the amplitude of the waves can be in excess of 80 m. As expected the amplitude and the number of IW increase as spring tide conditions are approached. Toward the end of the record, IW waves are detected for most of the time, i.e. other than at internal tide events. The waves are not confined in the upper 200 m but span at least the top 1000 m of the water column (figure 12). With only 2 drifting chains available to investigate the large-amplitude NLIW around spring tide, we did loose the ability to measure the local phase speed and direction of the waves. However, if we assume that the waves propagate to the west with a velocity c of 2 m/s and that the associated velocity field can be described by a functional form F(x-ct) the ratio of the vertical advective terms of the momentum equations to the time derivative can be computed. They all show that the non-linear terms are significant within the wave packet (figure 13). The velocity field associated with the internal waves supports large values of the vertical shear of the horizontal velocity

components. Several layers of high shear can be seen, normally associated with the internal tides. However, large values can be seen at other times and are always associated with internal waves that exist in the background (figure 14).

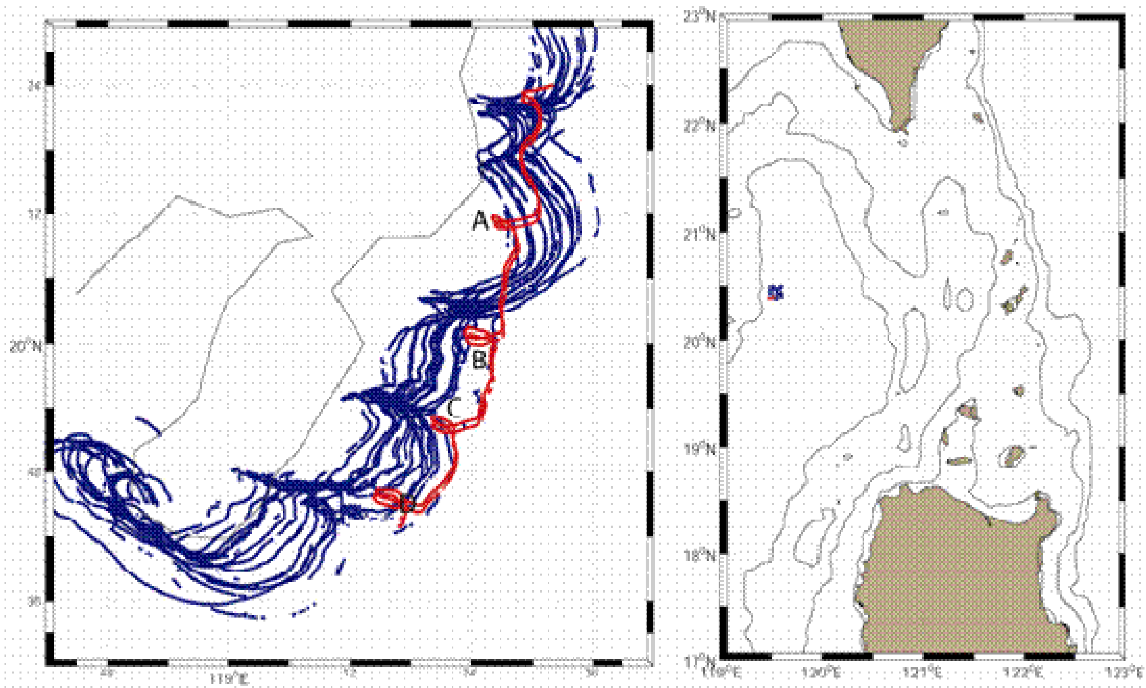

Figure 9: Tracks of 2 drifting chains (red) and 19 SVP drifters (blue) during NLIW E. On the right panel the deployment scheme is shown.

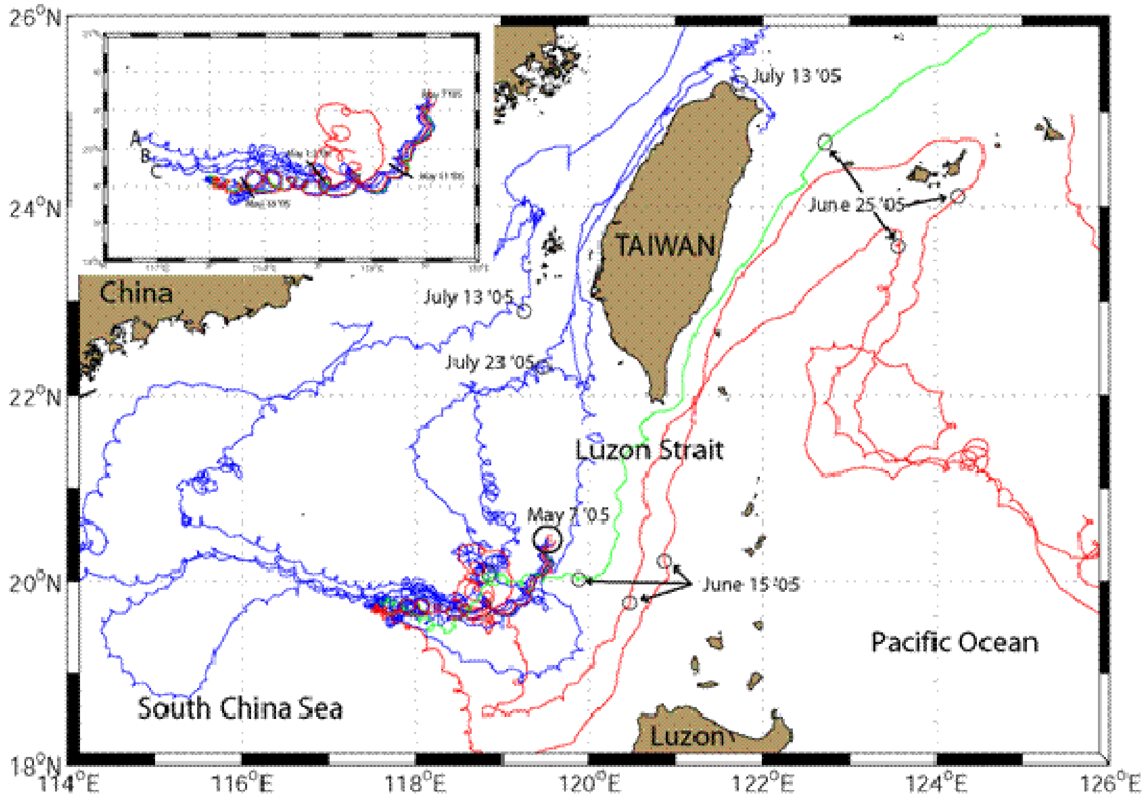

Figure 10: Selected trajectories of GPS-SVP drifters during and after NLIWE (see main text). The inset shows the details of the trajectories for 17 days after deployment. Cycloidal paths occur for the first 10 days and have the period of the diurnal tide. The drifters slowly separate into 2 groups as early as May 11, 4 days after deployment. On May 13 one drifter (red) re-circulates northward while the 3 other northernmost drifters (blue, labeled with A, B and C on the inset) slowly move apart from the rest of the array traveling westward. The remaining drifters describe a large tidal loop on May 18 (but smaller loops are present at later times) and then move very slowly. Absolute sea level plots suggest that the mesoscale eddy field has spatial scales of O(50-100 km) and time scales longer than 1 week, thus effectively stirring the drifters when their separation is comparable to the eddy scale. A saddle point of the sea level along the drifter paths starts to form on May 18 and evolves through May 25, dictating the different behavior and fate of the drifters labeled with A, B and C in the inset and the others.

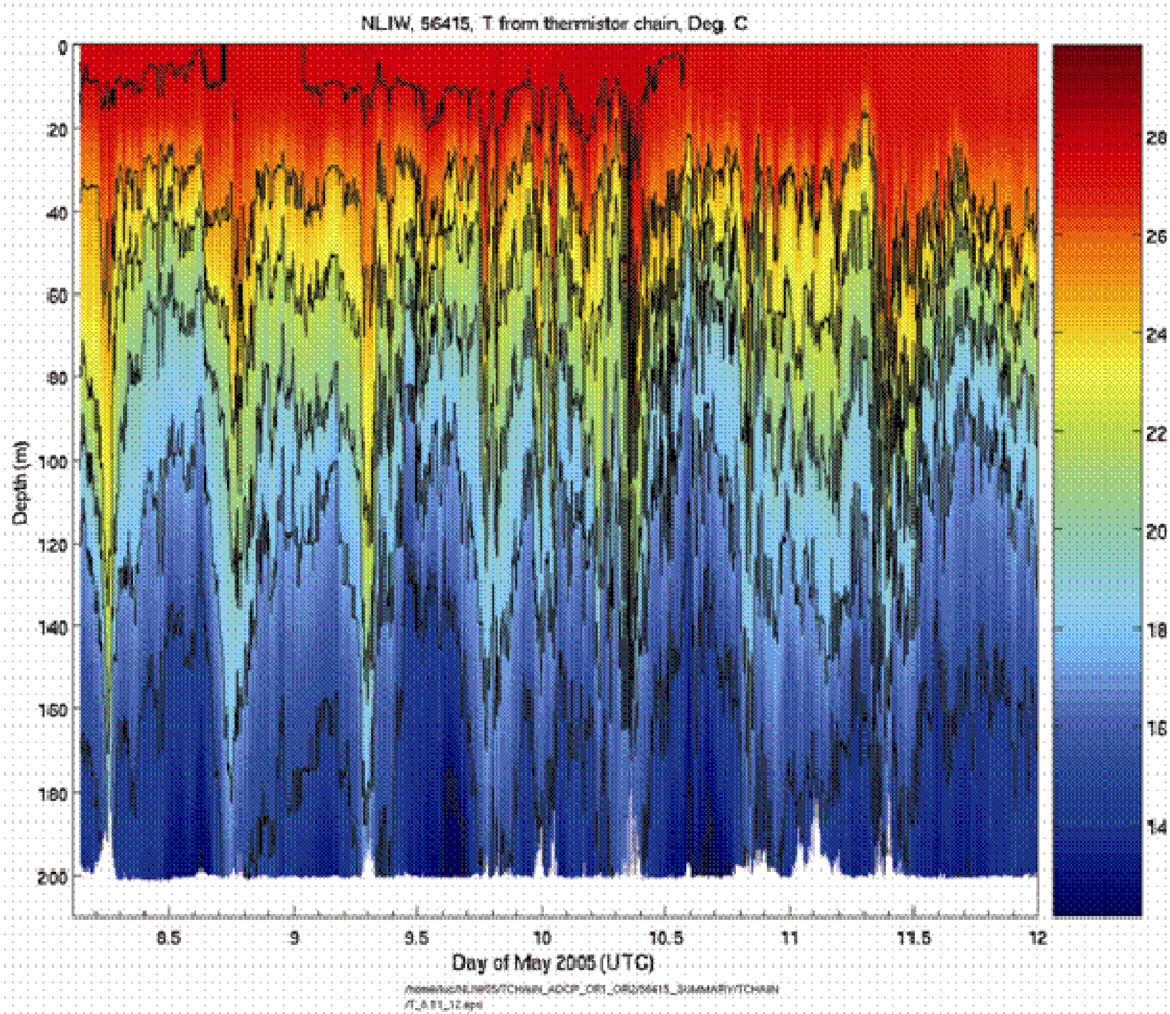

Figure 11: Temperature contours from one drifting chain taken during leg 2.

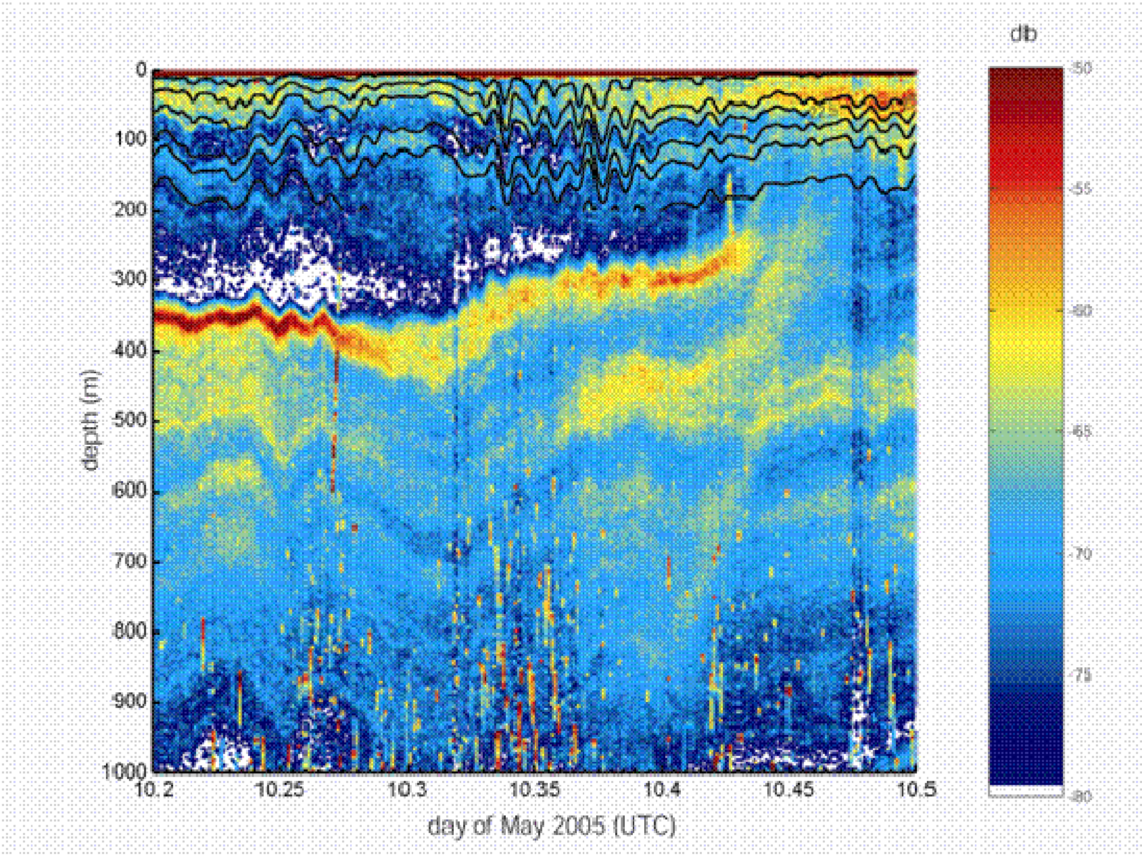

Figure 12: Attenuation from 38 KHz EK500 echosounder. The black lines are temperature contours from a nearby thermistor chain.

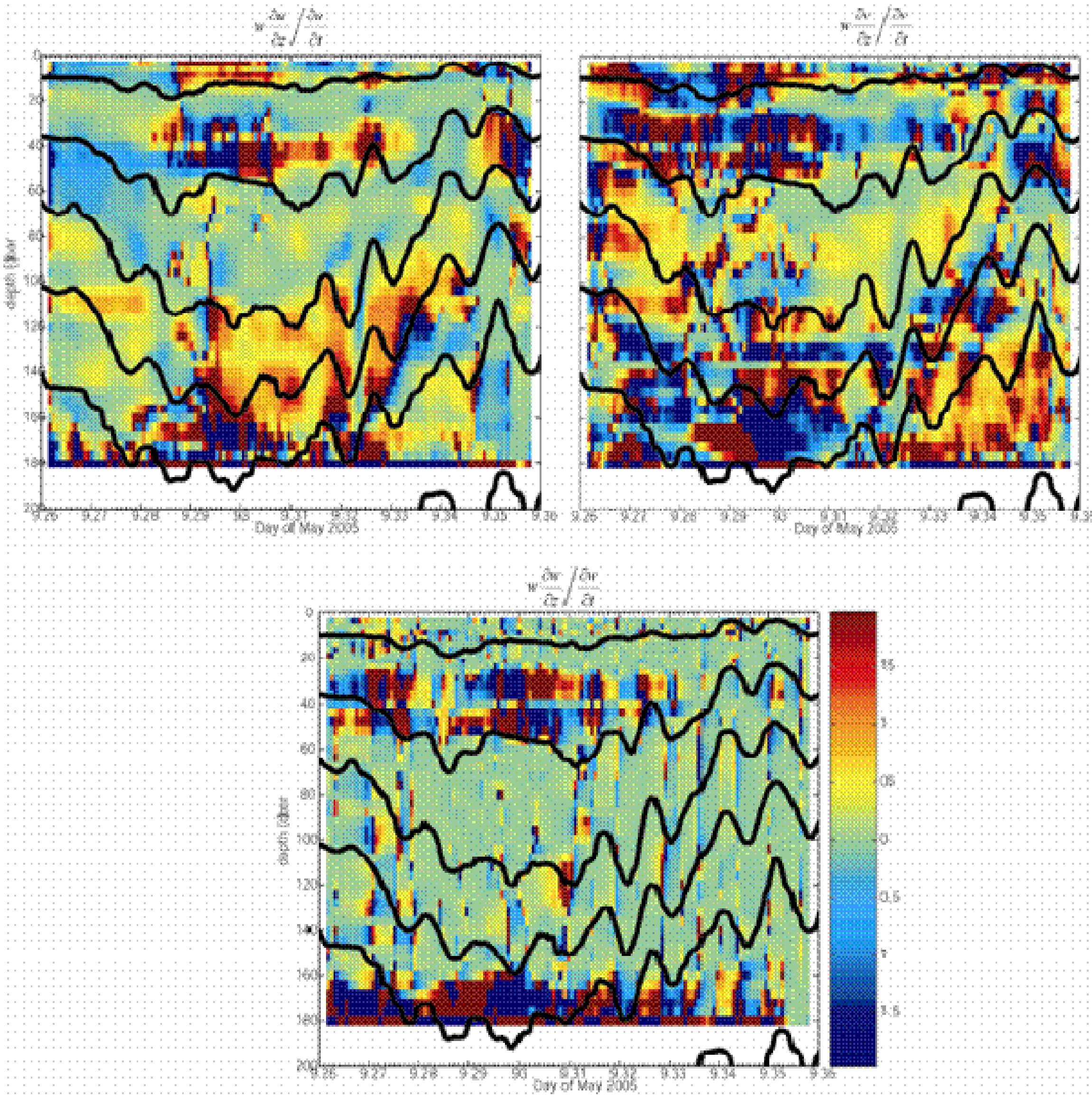

Figure 13: Ratio of 3 non-linear terms to the Eulerian time rate of change of velocity.

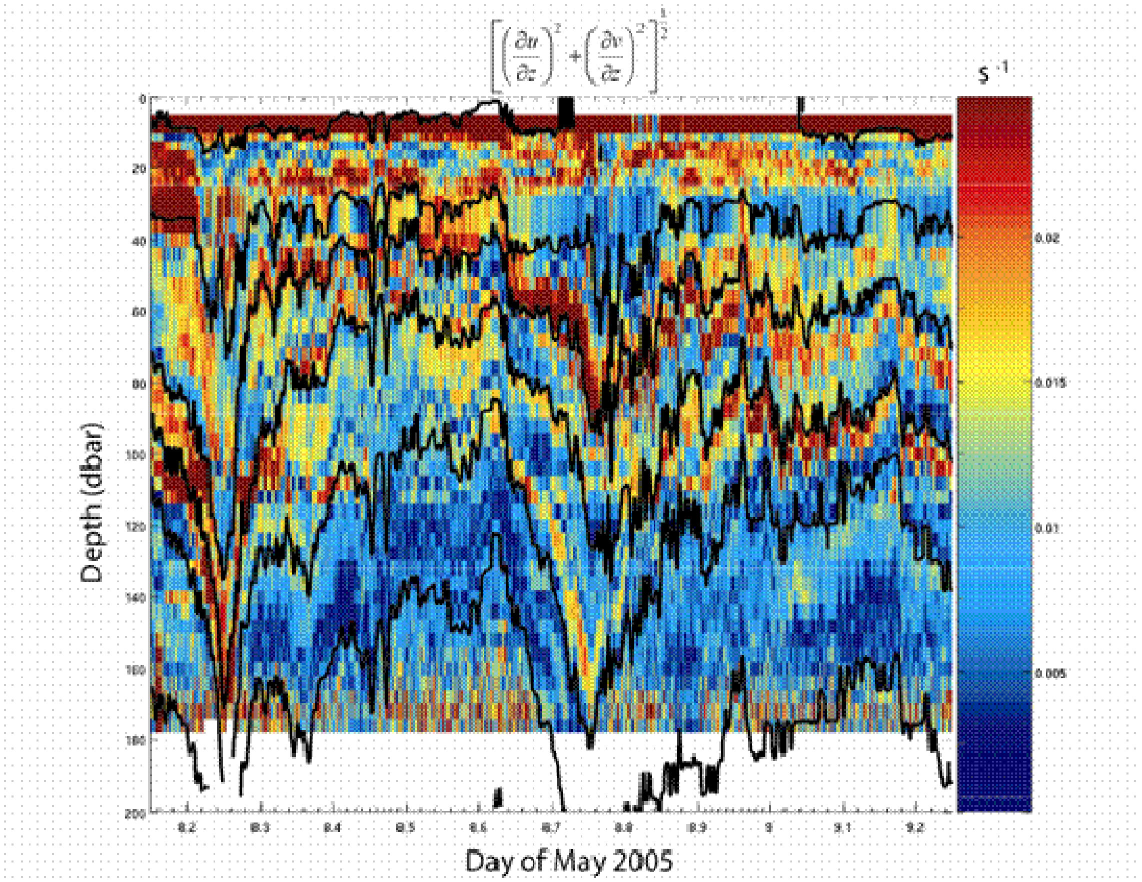

Figure 14: Vertical shear of the horizontal velocity.

IMPACT/APPLICATIONS

The drifter data were placed on the GTS for use by global scientific community.

TRANSITIONS

None

RELATED PROJECTS

NOAA/OGP funded the "Global Drifter Program"

PUBLICATIONS

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